

**[Nano device]**

# **Atomic-scale Observation of Surface Reactions and Chemical vapor Deposition in Real Time and Real Space**

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High-temperature scanning tunneling microscopy (VT-STM) has facilitated real-time, real-space investigation on surface atomistic processes and growth mechanisms during ultra-high vacuum chemical vapor deposition (UHV-CVD). In this talk, we shall report the atomic-scale observation of two prototypical semiconductor CVD growth systems: the Si(100) homoepitaxy using disilane and the growth of phosphorus on Si(100) using phosphine. Our real-time STM images show the evolution of molecular adsorption, surface morphology, atomic ordering, step advances, surface reconstructive transitions, hydrogen desorption, and spatial distribution of the surface dangling bond pairs during growth at temperatures between 300 and 700 C and clearly illustrate the atomic details occurred in UHV-CVD.

At a disilane pressure of around  $2 \times 10^{-8}$  torr, the Si growth on Si(100)- $2 \times 1$  at  $>570$  C proceeds with a pure step-flow mode at the initial stage. The growth at SB step is approximately three times faster than SA. After a single-domain surface is obtained, double-step flow growth occurs. Between 450-500 C, two-dimensional nucleation growth occurs. In addition, various amounts of H atoms are present on the surface, but do not prevent growth. The H atoms reduce the effective diffusion length of Si adatoms, leading to a large island density and ultimately causing an imperfection of layer-by-layer growth. Below approximately 400 C, the surface is passivated by various hydride species, thereby prohibiting multilayer growth. At temperatures approximately between 600-700 C, surface reconstructive transitions take place during growth.  $(2 \times n)$  defect structure is gradually formed initially. As growth proceeds, areas with  $c(4 \times 4)$  symmetry appear, grow, and eventually cover the entire surface.

During PH<sub>3</sub> exposure on Si(100) at high enough temperature, a surface phosphorus atom readily and randomly displaces one Si atom from the substrate. The ejected Si diffuses, nucleates, and incorporates itself into islands or step edges, leading to similar growth behavior as that found in Si chemical vapor deposition. Line defects both perpendicular and parallel to the dimer rows are observed on the nearly P-saturated surface. Perpendicular line defects act as a strain relief mechanism. Parallel line defects result from growth kinetics.

Hydrogen recombinative desorption from a Si<sub>2</sub>H<sub>2</sub> monohydride dimer on the Si(100) surface regenerates a dangling bond (DB) pair on the dimer. We investigated the temporal and spatial distribution of the regenerated DB pairs on the hydrogen-, disilane-, and phosphine passivated Si(100) surfaces in the temperature range between 320 and 370 K. The sequential images acquired in real time show that the ends of one-dimensional (1D) monohydride dimer islands are preferred sites for DB pairs and a repulsive interaction occurs between two neighboring DB pairs in the same dimer row.